AURORAL UV AND X-RAY EMISSIONS IN ANTARCTICA

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Abstract: The ultraviolet and X-ray features of the polar aurora were studied by means of the sounding rockets which were launched from Syowa Station, Antarctica in 1971. The distribution of energetic electrons was obtained from the data of the X-ray counters. The photometric data of the ultraviolet ionization chambers revealed a dual structure of the optical excitation in the active aurora.

1. Introduction

Two sounding rockets were launched from Syowa Station, Antarctica (geographical 69°00′S, 39°35′E, geomagnetic −66.7°, 72.5°) to explore ultraviolet and X-ray features of the polar aurora. They were single-staged, solid propellant rockets, 210 mm in diameter, and carried the payload weighing 25 kg to an altitude between 130 and 140 km. The payload consisted of the ionization chamber which detects the ultraviolet radiation of the aurora in the spectral region between 1100 and 1360 Å, and the scintillation counters which are sensitive to the X-rays having energies between 4 and 40 keV.

In this article we report briefly the results of preliminary analysis of the data obtained from these two auroral measurements. Since precise treatment of data is involved due partly to the complex geometrical structure of the aurora as well as the delicate motion of the rocket, and partly to the atmospheric modifications of the auroral radiations in the ultraviolet and the X-ray spectral regions, we shall restrict the discussion to several prominent features of the ultraviolet aurora in a somewhat qualitative manner. The X-ray result will be reported elsewhere, but some citation of it will be given in Sec. 4 because it would be conveniently used to locate spacial and time variations of the energetic electron source in the aurora.

2. Instrumentation

The ultraviolet detector used in the present experiments is the ionization chamber which is sensitive to radiations having wavelengths between 1100 and 1360 Å. The chamber is filled with 10 torr of pure nitric oxide gas. It has a

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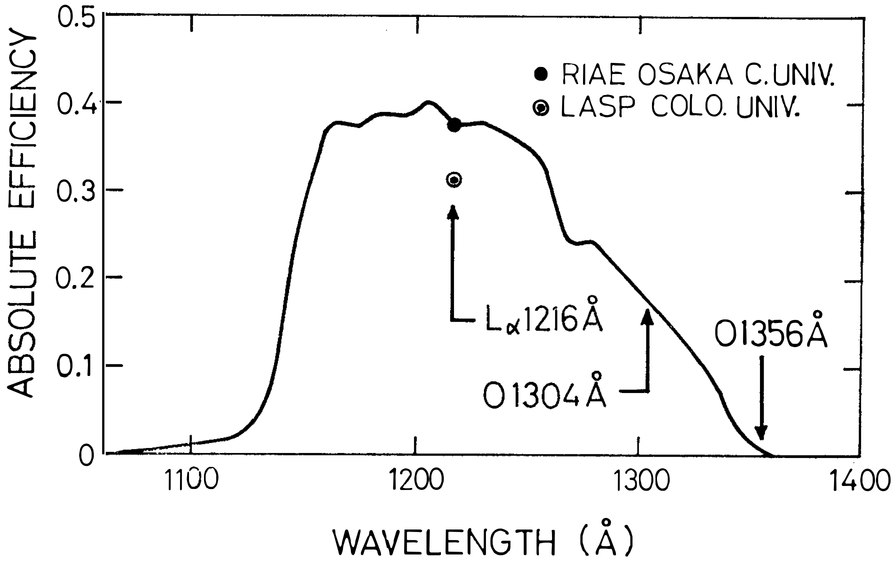

Fig. 1. Absolute quantum efficiency of the ultraviolet ionization chamber detector.

Table 1. Rocket launching data.

Rocket	S210JA2	S210JA3
Date	Sept. 25, 1971	July 22, 1971
Local Time	$00^h08^m01^s$	$00^h52^m01^s$
Apex altitude (km)	137	131
Detector orientation	Normal to spin axis	Parallel to spin axis

Table 2. Absolute quantum efficiency, typical relative intensity and O_2 absorption cross-section of auroral emissions.

Species	Wavelength (A)	Absolute quantum efficiency	Relative[3] intensity	O_2 absorption cross section (cm^{-2})
O	1152	0.24	110	2×10^{-20}
N	1200	0.39	3~5	1×10^{-18}
H	1216[1]	0.38	100	1×10^{-20}
O	1217	0.38	4~10	1×10^{-20}
O	1302-5-6	0.18	100	2×10^{-19}
N_2	1280~1430[2]	<0.2	50~100	$2\times10^{-19}\sim1.5\times10^{-17}$
O	1356	<0.05	5	6×10^{-18}

(1) Hydrogen Lyman-alpha.
(2) Lyman-Birge-Hopfield bands.
(3) The intensity of the atomic oxygen 5577Å is taken 100.

window made of magnesium fluoride crystal with an effective diameter of 8 mm and thickness of 1 mm. A honeycomb collimator is mounted head-on to the chamber giving it an approximately circular field of view of 10° in diameter.

The spectral sensitivity curve of the ionization chamber is illustrated in Fig. 1. The absolute quantum efficiency was calibrated through the courtesy of the Research Institute of Atomic Power of Osaka City University and the Laboratory for Atmospheric and Space Physics of University of Colorado. The two independent determinations of the absolute sensitivity at hydrogen Lyman-alpha coincide to each other with the error less than 10 percent. Values of the quantum efficiency at wavelengths of prominent auroral emission lines are listed in Table 2 along with their estimated emission rates (OMHOLT, 1971) and the photoabsorption cross-sections of molecular oxygen (HUDSON, 1971).

The S210JA3 had a pair of sodium iodide scintillation X-ray counters which are sensitive in the energy range between 4 and 40 keV. They were mounted back to back, making angles of 45° and 135° with the rocket's spin axis. Then the mapping of the sky in X-ray intensity was possible along the two circles having a radius of 45°.

3. Experiments on September 25, 1971

The sounding rocket S210JA2 was launched on September 25, 1971, at midnight (0^h08^m LT) when a homogeneous band of aurora of IBC class 2 was present in the zenith of Syowa Station. The band stretched from magnetic east to west. The rocket was launched in the direction of magnetic southwest so that in the ascent it passed through the southern edge of the band. The band was stable in structure but increased its brightness gradually during the flight.

The ground-based photometers recorded the intensities of atomic oxygen 5577Å and hydrogen H_β emission. The brightness of the 5577Å emission at the penetrated position was 2.5 kR in the ascent but it increased to 4 kR in the descent. The H_β intensity was stable at about 10 R during the flight. It would indicate that the primary excitation source of the aurora was energetic electrons having particle flux of $1\sim2\times10^9$ electrons$\cdot$cm$^{-2}\cdot$sec if a monochromatic initial energy of 10 keV was assumed (KAMIYAMA, 1966). On the other hand, the maximum particle flux of protons can be estimated to be less than 3×10^5 protons$\cdot$cm$^{-2}\cdot$sec^{-1} if a monochromatic initial energy of 30 keV is assumed (EATHER, 1967).

The ultraviolet detector was mounted on the rocket so as to place its line of sight normal to the spin axis of the rocket. As the rocket rolled at the rate of 1 Hz the detector scanned the sky along a great circle that inclined about 25° from the horizontal plane.

Figure 2 illustrates the altitude distribution of auroral brightness as observed in the ascent looking 25° upward and downward respectively from the horizontal plane; the same quantities in the descent are plotted in Fig. 3.

In the looking-down profiles one can readily see that there is no excitation source of the aurora below the 94 km level in the ascent and below 82 km in the descent. The looking-up profiles, on the other hand, suggest a double-layered

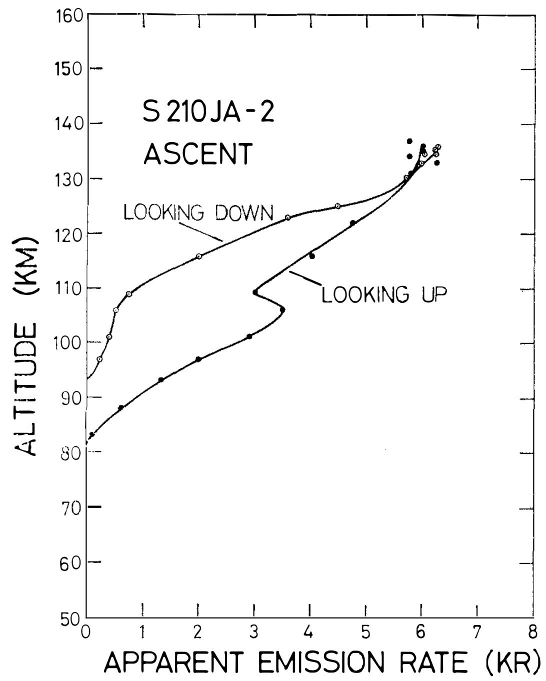

Fig. 2. Altitude profiles of the apparent emission rate observed in the ascent stage of S210JA2 flight.

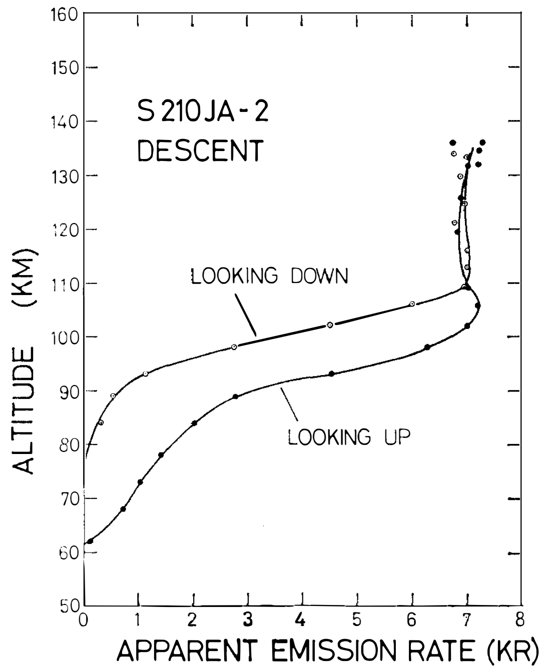

Fig. 3. Altitude profiles of the apparent emission rate observed in the descent stage of S210JA2 flight.

structure of the ultraviolet emission. The maximum emission rate of the lower layer appears around the 105 km level, suggesting the presence of either impinging electrons with energies larger than 10 keV or protons with energies larger than 30 keV. The monotonic increase of the apparent emission rate at altitude below 105 km is due primarily to the diminishing of the atmospheric extinction. The apparently slow rate of increase means that the probable emission species are hydrogen Lyman-alpha (1216Å) and/or the 1152Å emission of atomic oxygen whose wavelengths fall in the transmission windows of molecular oxygen. However, simple calculation using a comprehensive atmospheric model shows that the profile below 105 km cannot be totally reproduced in terms of the atmospheric extinction. The profile below the 105 km level seems to be significantly modified by spatial inhomogeneity and temporal change of the auroral structure, as the difference of the ascent and descent profiles indicates.

The emission feature above the 105 km level is quite different from that observed below. The apparent emission rate increases again with altitude irrespective of the direction of the detector till the apex of rocket is attained. From a comparison of the looking-up profile (downward intensity) with that looking-down (upward intensity) one can notice that the radiation field tends to be isotropic as the altitude increases. It is improbable that the atmospheric extinction comes into the mechanism of such emission distribution above 110 km since the optical thickness is too small for the ultraviolet in the pertinent spectral range.

4. Experiments on July 22, 1971

Another photometric experiment using the rocket S210JA3 was conducted on July 22, 1971 at 0^h52^m LT under the similar condition of aurora, and the photometric data were obtained in the altitude range between 70 and 138 km. The brightest band of aurora moved rapidly toward magnetic north before the rocket arrived at the auroral altitude, so that the detectors aboard the rocket could see only the auroral arcs far beyond the horizon of the launching site. The ultraviolet detector in this case was mounted so as to place its optical axis parallel to the rocket's rolling axis. But eventually a large precession of rocket occurred and the ultraviolet detector scanned along a circular strip of sky whose center of circle was directed to the azimuthal angle of 170° reckoned from north toward east, at the zenith distance of 20° and with half cone angle 85°. Consequently, the detector scanned the auroral arc at two different positions A and B indicated in Fig. 4 once for every precession cycle of the rocket.

The X-ray detectors were mounted at an angle of 45° off the rocket's spin axis, and then as the rocket preceded almost horizontally once every 20.5 sec and spun once every 0.8 sec they scanned along a cycloid locus over a circular zone having width of 90° containing the horizon. This peculiar motion of the rocket along with the special configuration of the X-ray counters enabled one to locate azimuthal distribution of the X-ray sources. Figure 4 is an isophoto-map of the

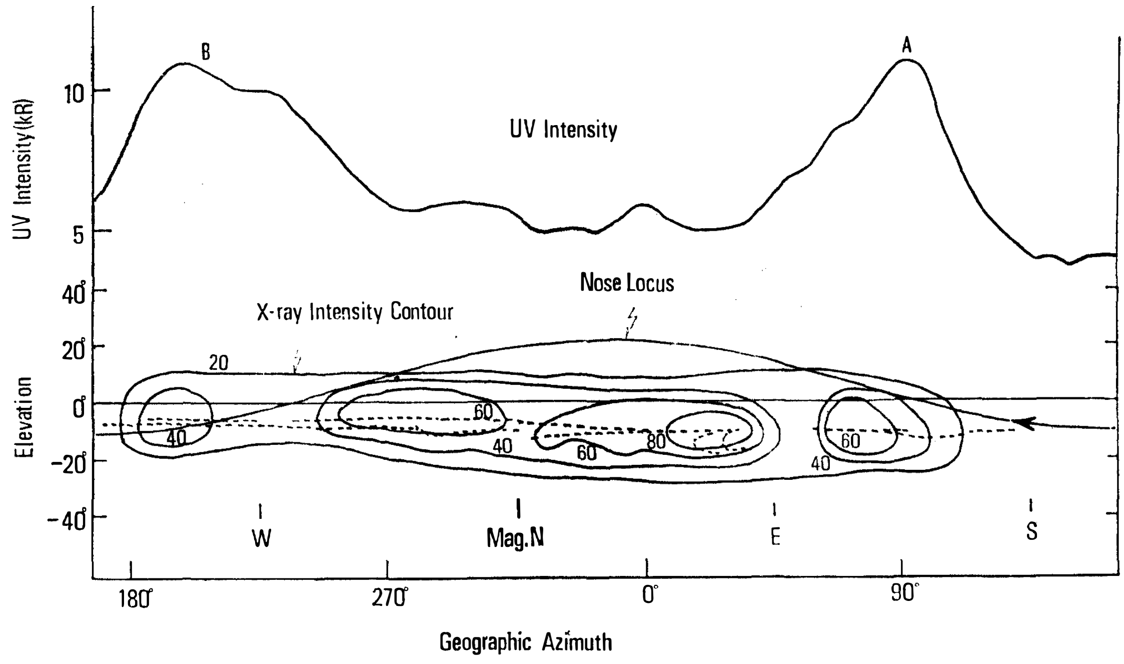

Fig. 4. The X-ray isophoto and the ultraviolet emission rate of the aurora observed on July 22, 1971.

X-rays measured during one cycle of the precession when the rocket was at the altitude between 125 and 130 km in the ascent. The dashed contours in Fig. 4 indicate schematically the position of auroral forms as estimated from the analysis of the all-sky camera photographs taken at Syowa Station. It is clearly seen that the X-rays are emitted from the same region of the atmosphere where the brightest auroral forms are seen. The distribution of X-rays looks wider than that of the optical auroras, but this is ascribed to instrumentation because of the wide-angled sensitivity of the detector. At the top of Fig. 4 is plotted the intensity of the ultraviolet radiation along the rocket's precession locus for comparison. It is observed again that the strongest ultraviolet emission appears at the same position where the brightest X-ray and visible auroras are found. But there is a remarkable difference that the spatial contrast of the ultraviolet intensity is much weaker than that of the X-ray.

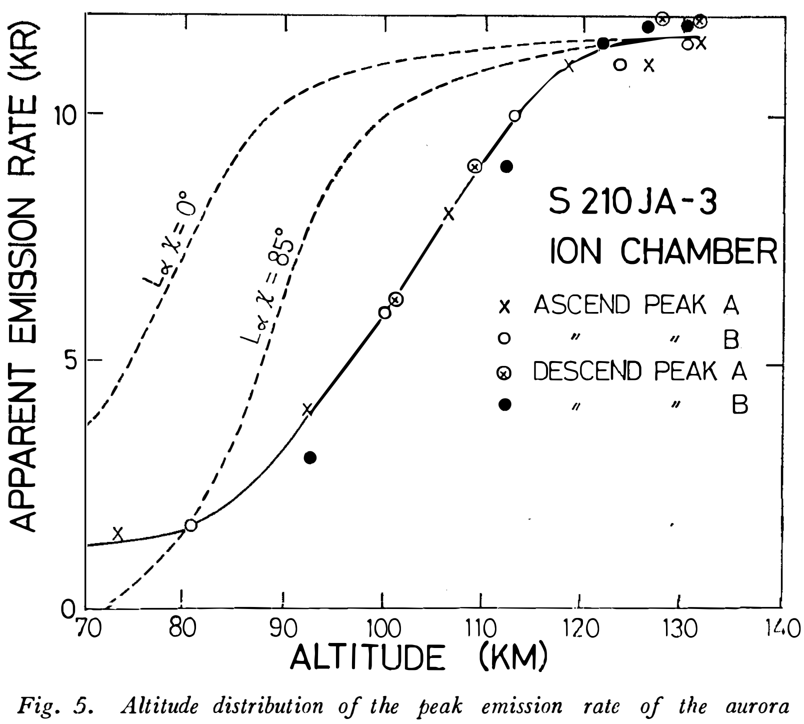

Fig. 5. Altitude distribution of the peak emission rate of the aurora observed by S210JA3 on July 22, 1971.

Figure 5 is the plot of the peak intensities of the ultraviolet emission when the detector's line of sight passed over the regions A and B in both ascent and descent stage of the flight. It is interesting to note that the four kinds of data point fit well on one altitude profile as shown in the figure. It is what could be expected as far as the ground observation revealed that the aurora was stable in position as well as in brightness during the flight. Also shown for comparison are the atmospheric extinction curves of the Lyman-alpha emission for the zenith distances of 0° and 85°.

The altitude profile thus obtained would be a consequence of the combined effect of auroral structure, the radiative transfer effect in the atmosphere and the geometry between the position of the rocket and the aurora. Because the detector aimed at the aurora nearly horizontally, the atmospheric extinction would be still significant even above the 120 km level. The 1302-5-6 Å triplet emission of atomic oxygen is the most probable source of the radiation as its optical depth is as large as 10^4 even above the 120 km level. However, the intensity below 110 km decreases more slowly in lower altitudes than expected for the 1300 Å emission.

Outside the auroral band a strong ultraviolet background was found which was considerably homogeneous and stable. The brightness of this background attained the maximum of 6 kR equivalent to hydrogen Lyman-alpha when measured at the zenith distance of 65° at the 120 km level, but it decreased gradually above that altitude. The geocoronal Lyman-alpha would more or less contribute to the formation of this kind of the background. But the observed brightness is too strong to be ascribed entirely to the geocorona because its optimum value at midnight is estimated to be less than 2 kR. Even the altitude profile of the background radiation is centered around the 120 km level. If the excitation source is energetic electrons, their initial energy will be less than 2 keV. On the other hand, if energetic protons are the source thier initial energy should be less than 10 keV.

5. Summary

The present observations revealed a dual structure of the ultraviolet aurora. The main excitation at the altitude of 105 km will be formed by energetic electrons with initial kinetic energy larger than 8 keV. This view is consistent with the result of X-ray measurement in the same flight. The ultraviolet radiation emergent from the auroral band seems to be primarily the atomic oxygen 1152Å. Although H 1216Å (Lyman-alpha) may be excited again by energetic protons its contribution is estimated to be small as inferred from the photometric measurement of H 4816Å (Balmer-beta) at the ground station. However, the ultraviolet radiation detected below the 90 km level seems to be largely contributed by the auroral as well as geocoronal Lyman-alpha emissions because of the window effect of O_2 photoabsorption. The O 1300Å triplet can be excited in a considerable amount, but it will be imprisoned within the main excitation region because the selfabsorption by a large amount of atomic oxygen is appreciable (TOHMATSU, 1964).

Outside the bright auroral band is found a background of ultraviolet emissions, which is considerably homogeneous in the horizontal and extends far above the visible structure. The radiation field of this background tends to be isotropic above 120 km. It is probably identical with the persistent 1300Å emission belt as discovered by using a polar orbit satellite in the auroral zone (PRINZ and MEIER, 1971).

The contamination of geocoronal Lyman-alpha is estimated to be less than

2 kR at the altitude above 120 km. However, because of the atmospheric window effect as mentioned before, the contribution of the geocoronal emission would be larger at altitude below 90 km.

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