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SPECTRAL CHARACTERISTICS OF LOW LATITUDE AURORAE ON OCTOBER 21, 1989

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Abstract: During the main phase of geomagnetic storm on October 21, 1989, the airglow spectrograph with a Schmidt camera of effective aperture *F*/0.7 observed distinct auroral spectra at low latitudes as in Niigata, geomagnetic latitude 27.7°, Japan. Although the aurora was not seen with the naked eye, it was observed by the method of ordinary airglow measurements, which required much longer exposure time. From the observed spectra, we can get the auroral components by subtracting a background spectrum which contains airglow and scattering city lights. We used a reference spectrum, which was constructed without aurorae under the same observing conditions of aurora spectrum. By subtracting the reference spectrum from that of observed spectrum, the following features emerged for the low latitude aurora on October 21, 1989: 1. Great enhancement in [OI] 6300 and 6364 Å doublet, whose intensities at the zenith were 6.7 and 2.0 kR respectively, 2. Enhanced [OI] 5577 Å emission of 1.4 kR at the zenith, and 3. no enhancements of N_2^+ 1.N. of 3914 and 4278 Å, [NI] 5200 Å, and of H Balmer alpha 6563 Å. These facts might suggest that precipitating particles responsible for this aurora are electrons with energy as low as $\sim$10 eV, and not positive and/or neutral particles.

1. Introduction

During the main phase of geomagnetic storm on October 21, 1989, the airglow spectrograph with a camera of effective aperture *F*/0.7, recorded strong auroral enhancements in the several emission lines of spectrum in the northern sky at low latitudes as in Niigata (latitude 37.7°N, longitude 138.8°E, and geomagnetic latitude 27.7°N), Japan.

Throughout the night, the aurora was *not seen* with the naked eye. Hence the spectrograph was operated by the method for regular airglow observations, which required several hours of exposure time. Although the duration of auroral activity was relatively short as thirty minutes or so, the auroral emissions were surely obtained from the spectrum, because of its strong brightness, by subtracting the background components containing the airglow emissions and other contaminations such as scattered city lights.

Spectral characteristics of low latitude aurorae were first the great enhancement in the emissions of [OI] 6300 and 6364 Å doublet (^1D-^3P) along with that of 5577 Å (^1S-^1D). However, in this aurora, N_2^+ 1.N. bands of 3914 and 4278 Å, Hydrogen Balmer alpha of 6563 Å and [NI] (^2D-^4S) of 5200 Å were not detected. The intensity ratio of 6300, 6364 Å to 5577 Å was 6. These facts are important to know the nature and energy of particles incoming to low latitude regions.

2. Airglow Spectrograph and Auroral Observations

2.1. Characteristics of spectrograph

2.1.1. Two rotatable right angled prisms placed in front of the entrance slit can simultaneously introduce the lights from northern and southern skies in the meridian plane into the upper and lower halves of slit respectively. By rotating each prism we can choose proper directions of northern and of southern skies. For the observations presented here N 76° and S 50° were selected as zenith distances.

2.1.2. The entrance slit is 48 mm in length and is divided into three parts, in which the two parts of 20 mm each are directed to the skies emitting aurora/airglow and the part of 8 mm is used for a comparison spectrum.

2.1.3. Two optical wedges, whose transmittances are 100 percent and 10 percent respectively, are placed in front of the entrance slit. The 10 percent wedge is effective for specifically strong light sources of aurorae, since it can surely avoid some over-exposure effects on the film.

2.1.4. A standard lamp with a known specific intensity (erg/cm^2 s Å steradian) and an optically neutral step wedge with several stages of transmittance are used. The present spectrograph has a tungsten lamp with a known temperature of 2670 K, which is calibrated by Matsuda standard lamp, and has a step wedge containing seven stages of transmittance, *i.e.* of 100, 50, 25, 12.5, 6.1, 3.1 and 1.5. These are used for the calibration of the intensity (Rayleighs) by measuring a photographic density exposed on the film.

2.1.5. Kodak 103a-F film of 16 mm width is used.

2.2. Main spectroscopical characteristics of spectrograph

Table 1. Spectroscopical characteristics of airglow spectrograph.

Field of view	6°
Wavelength region	3480 Å–6830 Å, Central wavelength 5130 Å
Linear dispersion	175 Å/mm, at 5130 Å
Theoretical resolving power	76000
Grating	Bausch & Lomb Co., Refractive grating
	600 lines/mm
	Blaze angle 8.38° at 5000 Å
	Size 128 × 154 mm
Collimator lens	Achromatic doublet
	Focal length 1200 mm
	Diameter 130 mm
Camera lens	Schmidt type
	Focal length 91 mm
	Diameter 130 mm $F/0.7$
Film width	16 mm
Slit	Length 48 mm
	Width 0.02–2 mm

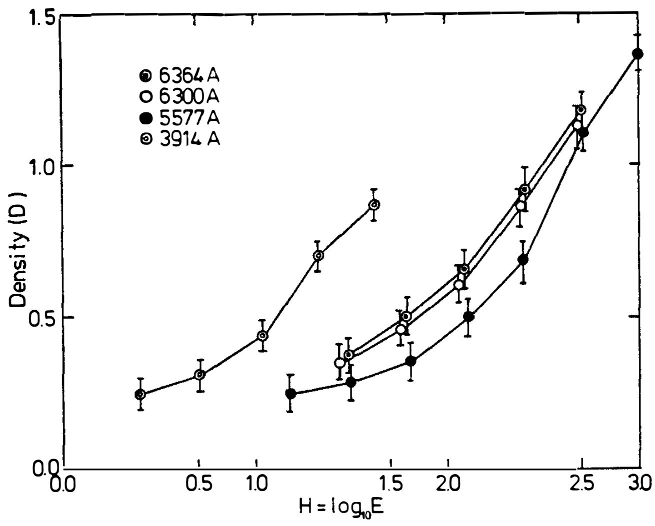

Fig. 1. H-D curves for wavelengths, where D is photographic density of film and $H=Log_{10} E$ for the exposed energy E on the film.

2.3. Method of calibration

The photographic density exposed on the film is usually converted into the intensity (Rayleighs) according to the method of photographic photometry, as summarized by the following steps.

2.3.1. To expose the light of standard lamp through the step wedge with the known transmittances (seven stages) on the same film of auroral spectrum.

2.3.2. To trace the densities of film made by the method of 2.3.1. using by Joyce Loebl Microdensitometer.

2.3.3. To plot the density D^*, that is, the microdensitometer readings, for the exposed energy E (erg/cm^2) on the film. Consequently we have the characteristic curve of the emulsion. Such a graph is usually shown in the form of "*H-D* Curve", where H is defined as $H=\text{Log}_{10} E$. In Fig. 1, *H-D* curves corresponding to each wavelength show the spectral sensitivity of a used film.

3. Spectral Results of Aurorae

Magnetic variations of the geomagnetic storm on October 21, 1989, observed at Kakioka (KUWASHIMA *et al.*, 1990; MIYAOKA *et al.*, 1990) show that low latitude aurora events appeared twice in the northern sky of Hokkaido, Japan, that is, at 1140–1200 UT and at 1410–1425 UT. Moreover, by the visual observations at night it was known that the auroral intensity of the second event was considerably weaker than that of the first one.

Auroral observations by the spectrograph at Niigata was carried out with the method of regular airglow observations at the low latitude, as geomagnetically 27.7° N, because no aurora was seen in the whole sky with the naked eye at that night. Two directions of sky were selected at N 76° and S 50°.

Northern sky is above the Japan Sea and far from city lights of Niigata, but it should be considered that the sky containing changeable intensities of aurora/airglow spectrum is inevitably much affected by strong scattered city lights. Southern sky

* D is defined as Log $(1/T_f)$, T_f is the transmittance of the film exposed.

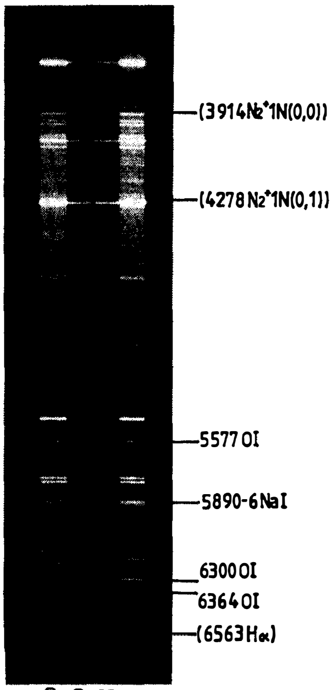

Fig. 2. Spectra, a to d, of low latitude aurorae observed at Niigata on October 21, 1989, for the different conditions of observational direction, zenith distance and of transmittance of the used optical wedge placed in front of the entrance slit. The top a shows the spectrum of northern sky, zenith distance 76°, and of wedge 100 percent transmittance.

above Niigata City is by far more affected.

Exposure time was nine hours, that is, 1000–1900 UT, and the width of entrance slit, 0.25 mm, corresponded to the resolution of 3.3 Å on the film plane.

Figure 2 shows the spectra of low latitude aurora observed at Niigata, consisting of four parts for the different conditions of observational directions, zenith distance (Z degree) and of transmittance (T percent) of used optical wedge placed in front of the entrance slit as follows: *a* $Z=76°$ north and $T=100$, *b* $Z=76°$ north and $T=10$, *c* $Z=50°$ south and $T=10$, and *d* $Z=50°$ south and $T=100$.

Auroral emissions are clearly recognized in the spectra of *a* and *b* in Fig. 2. Because the exposure time was very long, components of various sources other than aurora are relatively strong. For example, scattered city lights, especially Hg, Ne lines and continuous spectrum strongly appear. It should be noted that features of airglow components exist intrinsically in all the four spectra.

We can obtain the auroral component, by the aid of a reference spectrum, or auroral *free* spectrum at first, and then subtracting such the reference spectrum from the observed one: *i.e.* Fig. 2 *a*, which contains both aurora and the other components, as shown in eq. (1),

$$I_{aur}=I_{obs}-I_{ref}\ , \tag{1}$$

where I_{aur}, I_{obs} and I_{ref} denote the intensities of auroral, of observed, and of a reference spectrum, respectively. Here the reference spectrum is obtained by the spectrum of no aurora at night under the same conditions as the aurora observations.

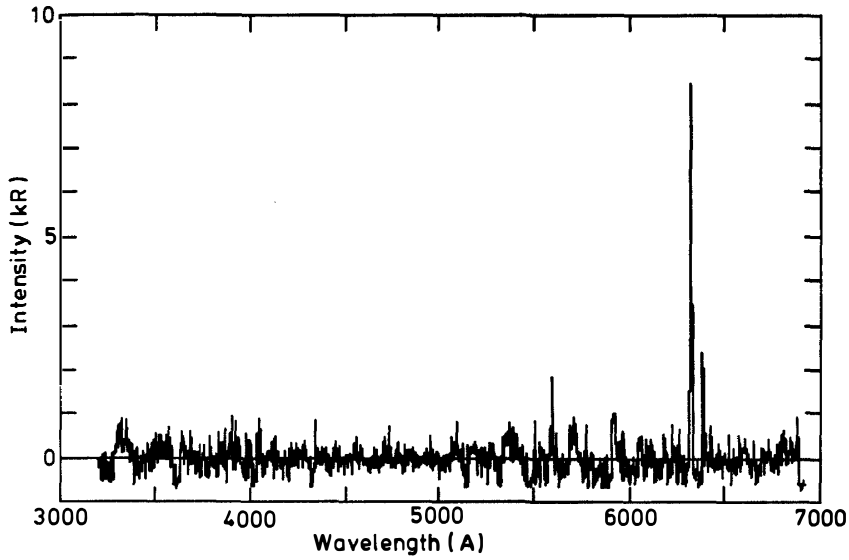

Fig. 3. Difference spectrum of the low latitude aurorae, at Z=76°. This is obtained from the observed spectrum by subtracting the reference spectrum which is the spectrum of no aurorae at night under the same conditions as aurora observation. Intensities are corrected for the lower atmospheric extinction.

Actually, I_{obs} is given by tracing the spectrum of Fig. 2 *a*, and I_{ref} is given by tracing the one of no aurora at night, that is, the previous day: October 20. These procedures for I_{obs} and I_{ref} are used in the following section of detailed analysis of individual emission lines.

Figure 3 shows I_{aur} which are corrected for the lower atmospheric extinctions at $Z=76°$

4. Detailed Analysis of Auroral Spectral Lines

To discuss spectral features of the observed aurora, a detailed analysis is required for the individual emission line as shown in Fig. 4, where both I_{obs} and I_{ref} are the intensities at $Z=76°$ and are corrected for the lower atmospheric extinction.

4.1. 6300 Å [OI] (^1D-^3P)

In Fig. 4-1, I_{ref} consists mainly of Ne spectrum of city lights, and the contribution from airglow emission is estimated to be very small. The intensity of 6300 Å from the aurora is estimated to be 8.6 kR.

4.2. 6364 Å [OI] (^1D-^3P)

In Fig. 4-2, I_{ref} for the background consists exclusively of city lights. The intensity of 6364 Å is from the aurora estimated to be 2.5 kR.

4.3. 5577 Å [OI] (^1S-^1D)

In Fig. 4-3, I_{ref} contains mainly airglow emission amounting to 320 Rayleighs on the average on the night of October 21, by photometrical observations. The in-

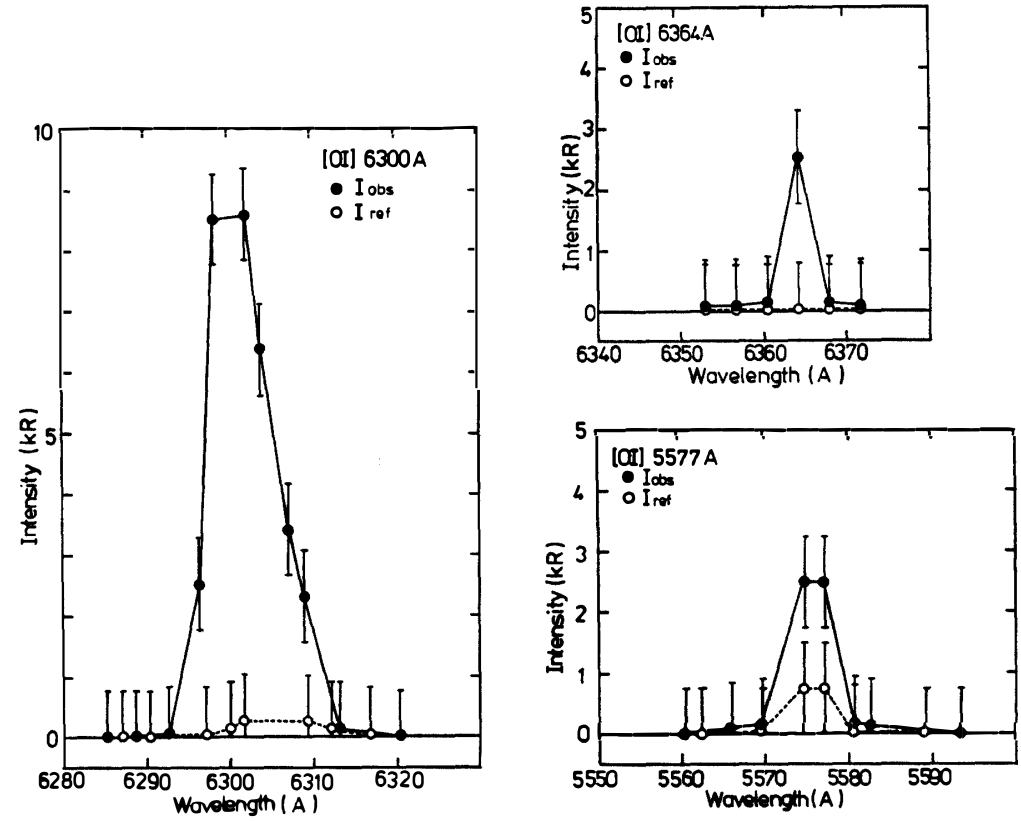

Fig. 4. Detailed analysis of auroral spectral lines of 6300 Å, 6364 Å, and 5577 Å. I_{obs} and I_{ref} are the intensities at $Z=76°$ and are corrected for the lower atmospheric extinction.

Table 2. Emission rates (Rayleighs) of low latitude aurorae. Intensity values refer to those at the zenith after the correction for the lower atmospheric extinction. Intensities of 3914, and 4278 Å of N_2^+ 1.N. bands, of 5200 Å of [NI], and of 6563 Å of H Balmer alpha are below the minimum detectable levels.

Element	Wavelength (Å)	Intensity
N_2^+ 1.N. (0, 0)	3914	<100 R
N_2^+ 1.N. (0, 1)	4278	<100 R
NI (^{2}D-^{4}S)	5200	<100 R
OI (^{1}S-^{1}D)	5577	1.4 kR
OI (^{1}D-^{3}P)	6300	6.7 kR
OI (^{1}D-^{3}P)	6364	2.0 kR
H Balmer alpha (^{2}D-^{2}P)	6563	<200 R

tensity of 5577 Å from the aurora is estimated to be 1.8 kR.

Thus obtained intensities at $Z=76°$ corrected for the atmospheric extinction may be referred to as the zenith values usually by the method of Van Rhijn coefficients. However such a method is in general not effective except the conditions that the emitting layer distributes uniformly over the whole sky as airglow phenomena. For the case of low latitude aurorae, because the emitting source is horizontally far apart from the observer and distributes locally in the sky, Van Rhijn coefficients should be changed by employing some effective assumptions. In this context, due to the observations in the northern area of Japan (MIYAOKA *et al.*, 1990; SAITO *et al.*, 1990), we introduce two assumptions that first the mean height of the emitting layer is 350 km and next the effective thickness of aurora-emitting layer is 50 percent of the total thickness of the layer, in the direction of $Z=76°$. We adopt 0.78 as the coefficient for converting the intensity of $Z=76°$ to the one at the zenith. Main results are summarized in Table 2.

5. Concluding Remarks

From the spectral results of the aurora observed, we obtained the two important facts. First, the intensity ratio of greatly enhanced emissions of 6300, 6364 Å to 5577 Å is 6, and second, N_2^+ 1.N. bands and H Balmer alpha line are under the minimum detectable levels. However, for the latter point, it should be noted that the lower atmospheric extinction coefficient is more effective in particular for the 3914 Å emission.

Concerning the two types of low latitude aurorae, for the source of incoming particles, TINSLEY (TINSLEY *et al.*, 1982, 1984) stated that direct, and or indirect precipitations of ions, and or energetic neutrals as the first type, and low energy electrons with kT $\sim$1 eV as the second one. Moreover, we had typical results of spectral characteristics of the greatest aurorae on February 11, 1958 (BELON and CLARK, 1959; CLARK and BELON, 1959; HIKOSAKA, 1958). Thus it will be possible to say that the spectral characteristics of the low latitude aurora on October 21, 1989, belong to the second type explained by TINSLEY, from the facts of the increasing of 5577 Å intensity precipitating electrons probably have $\sim$10 eV for their energy.

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