Rocket Observations of Visible and Ultraviolet Dayglow Features

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Abstract

Rocket results are presented on visible and ultraviolet dayglow observed in the altitude range of 80–350 km, for different values of solar zenith distance. Theoretical interpretations are given on the basis of calculations made for emission rates for various excitation mechanisms, also using results of simultaneous measurements of electron density and electron temperature.

1. Introduction

In the previous paper¹⁾, the writers presented the rocket results on the OI 6300 Å line and on the N_2^+ 3914 Å band in the dayglow. The experiment was repeated in the hour when the zenith distance of the Sun was large (approximately 90°). Also the present report includes the features of other visible and ultraviolet glow observed at Uchinoura, Japan. The names of vehicle used in the experiments were listed in Table 1 with the flight date, the time of launching, the solar zenith distance, and with the colors of the photometer flown.

Table 1. The Sounding Rocket Experiments of the Day Airglow, Uchinoura, Japan (131°05'E, 31°15'N)

Vehicle	Date	Time (JST)	Solar zenith distance	Color	
L-3-2	Jan. 31, 1965	14 : 01	54°	2150 Å 2000–3000 Å	
K-9M-9	Mar. 27, 1965	14 : 01	37°	6300 Å 2500 Å	3914 Å 2150 Å
K-9M-20	Oct. 20, 1966	17 : 25	88°–91°	6300 Å 5200 Å	5577 Å 3914 Å

The analysis of records proceeded on the theoretical background which took into consideration the various excitation mechanisms as listed in Table 2. Among the mechanisms of Table 2, the photoelectron excitation was not considered in the previous study¹⁾ and was newly evaluated its contribution²⁾. Also shown in Table 2 was the rank of the brightness from different mechanisms as expected from theory.

The electron density profiles which were measured simultaneously with the present dayglow observations are plotted in Fig. 3. They were used to determine the rate of the DR processes, the density of N_2^+ , and further to evaluate the stopping power of electron-electron

Tabel 2. The Mechanism of the Dayglow Excitation (The rank of contribution to the total brightness is indicated as I, II, and III)

Excitation Mechanism	Symbol	6300 Å	5577 Å	3914 Å	UV
Resonance fluorescence of solar radiations	RF	—	—	I	(I)
Simultaneous ionization and excitation by solar ultraviolet radiations	SIE	—	—	II (day) III (sunset)	—
Simultaneous dissociation and excitation (Schumann-Runge dissociation)	SR	I	(III)	—	—
Photoelectron impact excitations	PE	II	(I)	II (sunset) III (day)	(II)
Chemiluminescence (Dissociative recombination)	DR	III	(II)	—	—

Fig. 1 The calculated emission rate profiles of the OI 6300 Å glow for various excitation mechanisms, corresponding to the sunset condition (K-9M-20).

interaction which is important for the calculation of the photoelectron energy spectrum above the 250 km level.

Figs. 1 and 2 illustrate the calculated emission profiles for various excitation mechanisms of the 6300 Å and 3914 Å emissions respectively.

2. The 6300 Å Emission

To compare with the observed emission profile of the 6300 Å dayglow, the excitation rates of the following were evaluated.

- (i) Schumann-Runge dissociation of O_2 by solar ultraviolet radiations (SR)

- (ii) Impact excitation of oxygen atom by solar XUV producing photoelectrons

- (iii) Dissociative recombination of O_2^+ and NO^+ with electrons

In the previous analysis¹⁾, the processes (i) and (iii) were quantitatively studied. However, the process (ii) would be found to be important in the daytime excitation of the

Fig. 2 The calculated emission rate profiles of the $\text{N}_2+3914 \text{ \AA}$ glow for various excitation mechanisms, corresponding to the sunset condition (K-9M-20).

Fig. 3 The electron density profiles measured simultaneously with the present dayglow experiments (Courtesy of Prof. K. Hirao and Dr. H. Ôya).

6300 Å emission.

The curves indicated by SR, PE, and DR in Fig. 4 show the altitude distributions of the 6300 Å emission rate computed for the processes (i), (ii), and (iii) respectively. The DR-profile is obtained using the observed electron profile applied to the reaction rate coefficients, $k_{3A}=3\times 10^{-12}$, and $k_{3B}=3\times 10^{-13}$ cm³/sec. The RE-profile is calculated on the basis of the electron energy flux spectrum after Ogawa²⁾. The nitrogen molecule is considered as a quenching agent, with the rate coefficient of 2×10^{-11} cm³/sec.⁹⁾ The altitude distributions of atmospheric parameters were taken from CIRA Model 2, Hour 14³⁾.

Similar calculations were repeated for the condition of K-9M-20, using the atmospheric parameters taken from CIRA Model 4, Hour 18. In Fig. 5 the integrated emission profile observed by K-9M-20 is compared with those calculated for SR, PE, and DR processes. In Figs. 4 and 5 one may notice that the observed profile is in favor of the theory which takes into account the photoelectron excitation. The rather slow decrease of the emission rate above 200 km cannot be explained by the SR- and DR-excitations alone. The results are summarized in Table 3. The observations show larger amplitude of variation of the 6300 Å brightness than that obtained in the calculation. The observation in the sunset condition is particularly

Fig. 4 Comparison of the observed and calculated emission profiles of the 6300 Å dayglow observed in daytime condition (K-9M-9).

Fig. 5 Comparison of the observed and calculated (integrated) emission profiles of the 6300 Å dayglow, observed in the sunset condition (K-9M-20).

Table 3. The Calculated Emission Rate of the 6300 Å Dayglow below the 350 km Level

Solar zenith distance		37°	88°-91°
Corresponding flight		K-9M-9	K-9M-20
Emission rate (kR) (Theory)	SR	3.1	2.5
	PE	1.7	1.5
	DR	0.6	0.5
	Total	5.4	4.5
Observed emission rate (kR)		6.1	3.6

likely to indicate a smaller contribution of the SR glow than that can be extrapolated from the daytime result.

3. The 5577 Å Emission

The 5577 Å emission of atomic oxygen was observed only in the sunset condition. The record evidently indicates the presence of the two emitting layers, of which one is narrow and lies between 90 and 120 km, and the other is broad and spread in the altitude range, 150-300 km. The integrated emission rates are estimated to be about 400R and 300R for the narrow and broad layers, respectively. The scatter of the observed intensities did not permit the further quantitative analysis of the altitude distribution of the emission rate, however.

4. The 3914 Å Emission

To compare with the observed emission profile of the 3914 Å dayglow, the excitation rates of the following processes were evaluated.

- (i) Resonance fluorescence of solar 3914 Å radiation by N_2^+ ion (RF),
- (ii) Simultaneous ionization and excitation of N_2 molecule by solar XUV radiations (SIE),
- (iii) Impact excitation of N_2 molecule by solar XUV producing photoelectrons (PE).

In the computation of the RF excitation rate, the equilibrium N_2^+ density was obtained from the computed N_2^+ source balanced with various removal processes of $N_2^{+4,5}$. The scattering coefficient was taken as 0.050 after Broadfoot⁶⁾.

As summarized in Table 4, a large amplitude of intensity variation is expected for the 3914 Å emission. This expectation is well demonstrated in the two experimental results illustrated in Fig. 6.

Fig. 6 Comparison of the observed and calculated (integrated) emission profiles of the 3914 Å dayglow observed in two different conditions. —: observed, — — —: calculated for the daytime condition (sum of RF+SIE+PE. - - - -: calculated for the sunset condition (sum of RF+SIE+PE).

Table 4. The Calculated Emission Rate of the 3914 Å Dayglow below the 350 km Level

Solar zenith distance		37°	88°–91°
Corresponding flight		K-9M-9	K-9M-20
Emission rate (kR)	RS	1.39	0.66
	PE	0.45	0.05
	SIE	0.98	0.03
	Total	2.82	0.74
Observed emissson rate (kR)		3.3	0.4

5. The Glow in the 2000~3000 Å Range

An ultraviolet glow was observed by the wide-dand photometer which was sensitive to radiation between 2000 and 3000 Å. It was detected in the altitude ranges between 93 and 115 km. The brightness in equivalence to 2500 Å radiation was approximately 10 kR at 93 km, and decreased to 3 kR at 115 km. This brightness is too large to be interpreted by the Rayleigh scattering of solar radiations, and decreased with altitude more slowly than it should. It was not observed in the records of narrow band photometers sensitive to the radiations near 2150 Å and 2500 Å. Therefore, the emission is likely to spread over the wide range between 2000 and 3000 Å. The emission may be ascribed to the unresolved bands of Schumann-Runge system of O₂. Tohmatsu⁷⁾ estimated that the resonance fluorescence of solar radiation by O₂ may result in a ultraviolet glow in the mesosphere and lower thermosphere. However, the estimated intensity is larger than the observed, even by a factor of 20. It would mean that the efficiency of fluorescence is as low as 0.05, if the observed emission is ascribed to the Schumann-Runge glow. This result is consistent with the spectroscopic observation by Barth⁸⁾.

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