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THE ATMOSPHERE EXPLORER OPTICAL GLOW NEAR PERIGEE ALTITUDES

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Abstract. The altitude variation of the Atmosphere Explorer optical glow intensity suggests that two different processes are responsible for the glow. One, dominant for altitudes above 180 km, has an emission brightness proportional to the ambient atomic oxygen density whereas the other, dominant at altitudes below 160 km, produces an emission whose intensity is proportional to the product of the densities of any of N_2, O_2 or NO. The first mechanism apparently has two components, one from the surface recombination of O and H and the other from a process similar to that producing the Shuttle glow. Unless the efficiency of the second mechanism is much enhanced on the Shuttle its contribution to the Shuttle glow is negligible.

Introduction

The existence of an optical glow associated with the Atmosphere Explorer satellites was noticed by Torr et al. [1977]. The characteristics of the glow were studied by Yee and Abreu [1982, 1983] and by Yee et al. [1984] who showed that at altitudes above about 160 km the glow intensity was directly proportional to the density of atomic oxygen and that if the glow is produced by metastable molecules released from the surface with thermal velocities the angular distribution of the glow was consistent with a radiative lifetime of the emitting molecules of about 5 ms. The ratio of the intensity of the glow at 732 nm and 656 nm [Yee and Abreu, 1982] was 2.25 at altitudes between 140 and 145 km and 2.15 between 170 and 175 km [Langhoff et al., 1983]. Yee and Abreu [1983] drew attention to the laboratory studies of surface-catalyzed excitations of OH, NO and NO_2 band systems. Slanger [1983] pointed out that the intensity ratio is comparable to that observed for OH emission in the night airglow and suggested that the rotation-vibration bands of OH are the source of the glow. Data over a more extensive spectral range [Yee and Abreu, 1983] were not consistent with the OH night airglow emission but Langhoff et al. [1983] showed that the identification of OH as the glow species could probably be maintained by postulating an association mechanism on the satellite surface in which the vibrational levels of OH are populated uniformly. Yee and Abreu [1983] had demonstrated that a marked change in the scale height of the glow intensity occurred at about 140 km and that the glow spectrum was slightly modified. Slanger [1983] concluded that the enhanced intensity of the glow below 160 km is proportional to the density of molecular oxygen and implied that at low altitudes vibrationally excited OH is produced by a surface reaction with O_2.

A similar optical glow is observed in the ram direction of the Shuttle orbiter [Banks et al., 1983] though with different spectral characteristics and with a different spatial extent [Mende et al., 1983, 1984, 1985; Yee and Dalgarno, 1984; Swenson et al., 1985]. Green [1984] has suggested that it arises from the recombination of nitrogen atoms into high vibrational levels of the A $^3\Sigma_u^+$ state of N_2 which decay sequentially to vibrational levels of the B $^3\Pi_g$ state to lower vibrational levels of the A $^3\Sigma_u^+$ state, a mechanism postulated by Weinreb and Mannella [1969] to explain laboratory measurements of the luminescence produced by surface recombination of nitrogen atoms in the presence of small amounts of electrically discharged oxygen. Mende et al. [1985] and Swenson et al. [1985] have shown that the Shuttle glow has the spectral appearance of the $NO_2(^2B_1)$ recombination continuum [Fontijn et al., 1964; Paulsen et al., 1970; Kenner and Ogryzlo, 1984; Kuwabara et al., 1984], and they advocate a mechanism in which nitrogen atoms and oxygen atoms recombine on the surface to form NO which then reacts further with the ambient energetic oxygen atoms.

Because surface glows may place design constraints on projected shuttle-based astronomical and atmospheric observations, it is important to understand more clearly the origins of the Atmosphere Explorer and Shuttle glows. We present here a study of the Atmosphere Explorer emission at altitudes below 160 km. We show that after subtraction of the contribution from the high altitude atomic oxygen mechanism, the

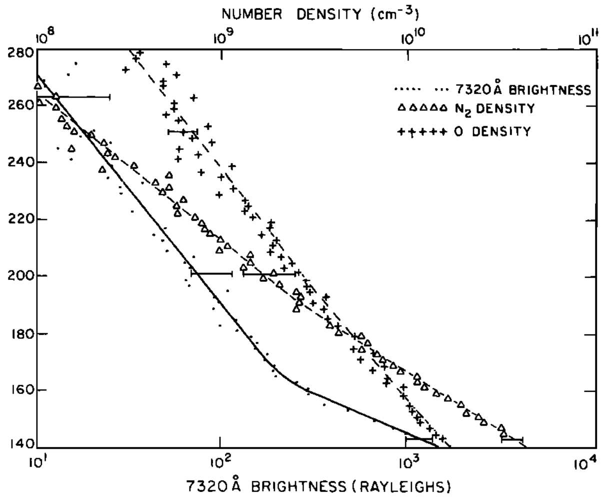

Fig. 1. The intensity of the glow at 732 nm in Rayleighs as a function of altitude.

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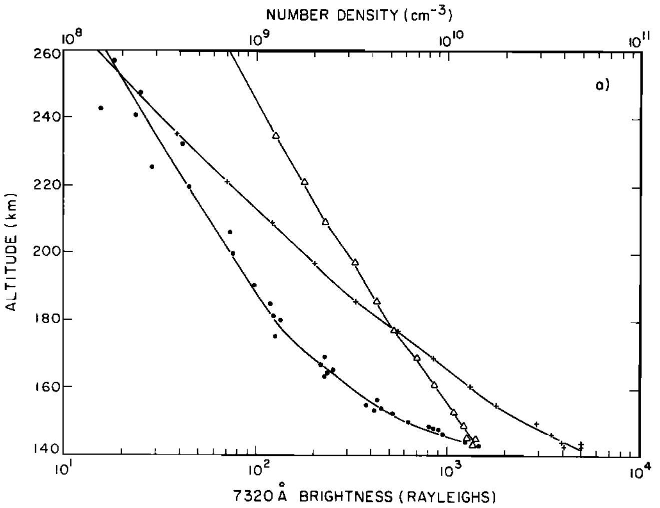

Fig. 2a. The intensity of the glow in Rayleighs, indicated by ●, and the ambient densities indicated by Δ for atomic oxygen and + for molecular nitrogen, measured on orbit 1336.

residual emission brightness is proportional not to the density of molecular oxygen but to the product of the densities of any pair of molecular nitrogen, molecular oxygen and nitric oxide suggesting a mechanism which involves the successive collisions of two molecules.

Atmosphere Explorer Glow at 732 nm

The intensity of the Atmosphere Explorer glow at 732 nm is shown in Figure 1 as a function of altitude [Yee and Abreu, 1982]. The altitude variation has two scale heights. Yee and Abreu [1983] suggested that more than one source of emission exists or that the source was time-dependent.

Figures 2a and 2b show the altitude glow and ambient density profiles obtained on orbits 1336 and 1311. At 143 km, the intensity measured on orbit 1336 is ~500 Rayleighs less than that measured on orbit 1311. The atomic oxygen densities during the two orbits were similar but the molecular nitrogen densities were lower during orbit 1336 when the low altitude glow was weaker than during orbit 1311. It seems that N_2 is participating in the creation of the low altitude glow though the possibilities that O_2 and NO are responsible cannot be excluded if their densities varied as did the N_2 density. However we will label the mechanism by N_2.

The high and low altitude sources may be separated by extrapolating the high altitude brightness to low altitude using the measured atomic oxygen densities. The residual I_{N_2} dominates the glow at low altitudes. Figures 3a and 3b show the results for orbits 1336 and 1311.

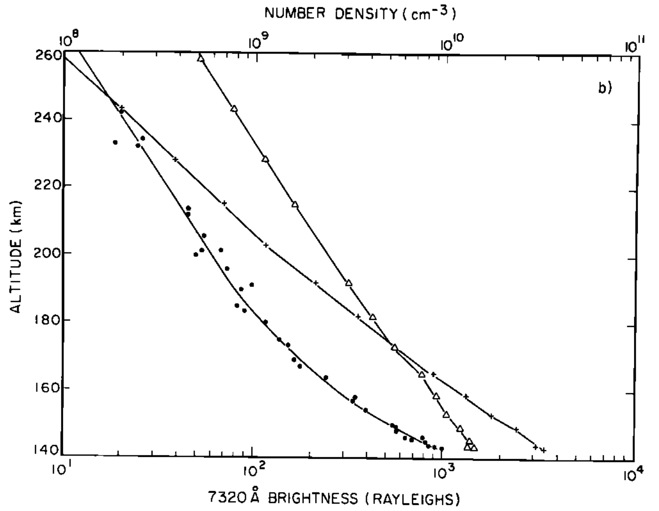

Fig. 2b. As for Fig. 2a on orbit 1331.

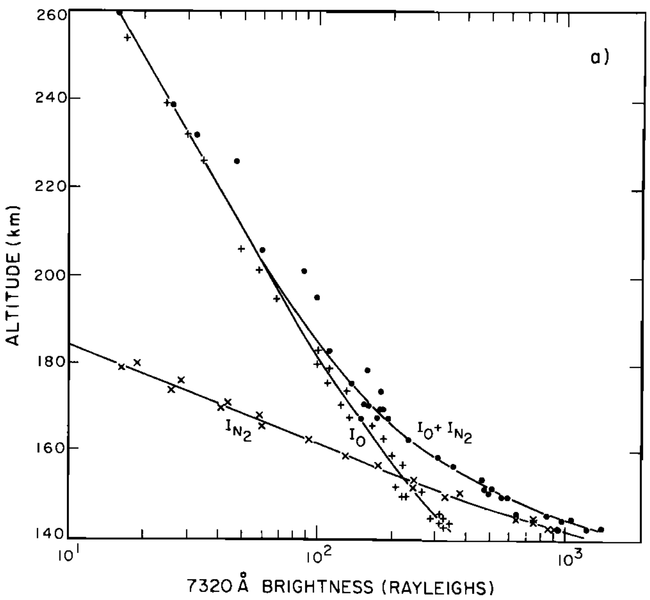

Fig. 3a. The glow intensity at 732 nm in Rayleighs on orbit 1336 indicated by ● and the separate contributions from the oxygen mechanism + and the nitrogen mechanism x. The fits are labelled respectively $I_O + I_{N_2}$, I_O and I_{N_2}.

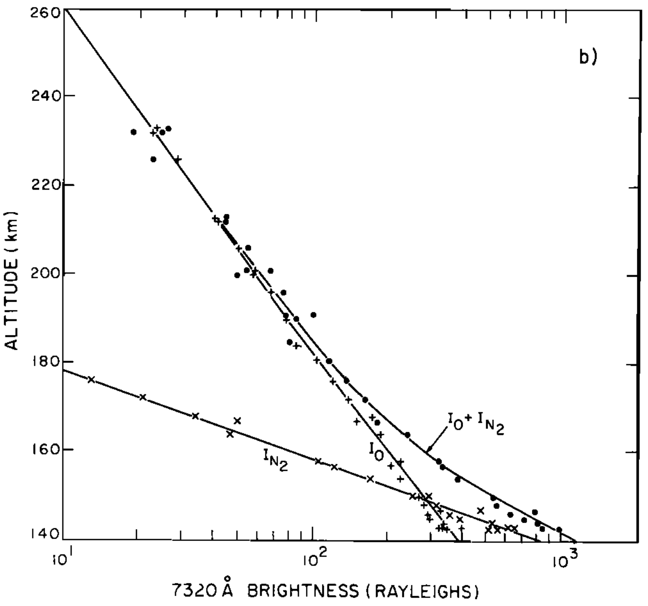

Fig. 3b. As for Fig. 3a on orbit 1311.

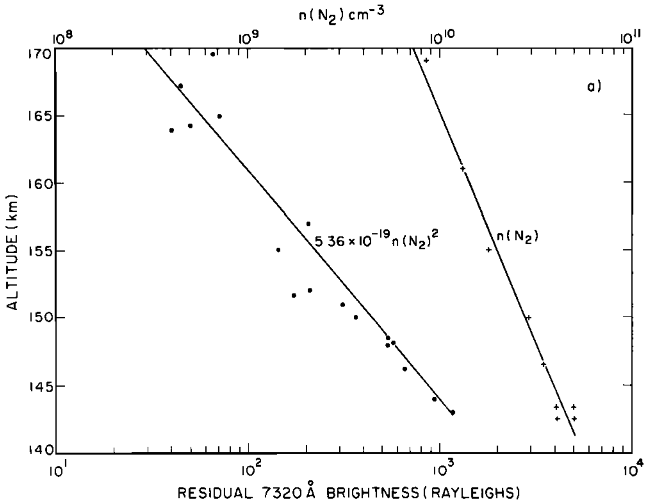

Fig. 4a. The residual brightness on Rayleighs on orbit 1336 after subtraction of the contribution proportional to [O] represented by ● and the number density $[N_2]$ represented by +. As indicated, the points lie approximately on the straight line $5.36\times10^{-19}[N_2]^2$.

TABLE 1

Rate coefficients $k(\lambda)$ and $k(\lambda)/\Delta\lambda$ for O and N_2*

λ(nm)	k_O(R cm^3)	$\frac{k_O}{\Delta\lambda}$ (R cm^3 nm^{-1})
732	2.41(-8)±5.83(-10)	1.07(-8)±2.59(-10)
656	1.71(-8)±3.93(-10)	7.28(-9)±1.75(-10)
428	4.25(-10)±1.32(-10)	2.02(-10)±6.29(-11)
337	1.10(-9)±2.37(-10)	3.92(-10)±8.46(-11)
280	1.83(-9)±2.43(-10)	3.32(-10)±4.41(-11)
	k_{N_2} (R cm^6)	$\frac{k_{N2}}{\Delta\lambda}$ (R cm^6 nm^{-1})
732	5.05(-19)±1.66(-20)	2.24(-19)±7.38(-21)
656	4.31(-20)±8.57(-21)	1.83(-20)±3.77(-21)
428	3.05(-20)±1.84(-21)	1.45(-20)±8.76(-22)
337	1.08(-19)±5.72(-21)	3.86(-20)±2.04(-21)
280	9.52(-20)±4.26(-21)	1.73(-20)±7.74(-22)

*R ≡ 1 Rayleigh = 10^6 photons cm^{-2}s^{-1}.

We attribute I_{N2} tentatively to a mechanism involving N_2. Its altitude variations are compared in Figures 4a and 4b to those of the N_2 number densities. The scale heights of I_{N2} are equal to within measurement error to one half of those of N_2 and we may write

$$I_{N2} = k_{N2}[N_2]^2 \qquad (1)$$

where $[N_2]$ is the number density of N_2 and k_{N2} is a constant. For orbit 1311, $k_{N2} = 5.36\times10^{-19}$ Rayleighs cm^6 and for orbit 1336, $k_{N2} = 5.50\times10^{-19}$ Rayleighs cm^6. Thus the glow intensity at 732 nm can be reproduced over the entire range of altitudes above 143 km by the empirical formula

$$I = k_O[O] + k_{N_2}[N_2]^2 \qquad (2)$$

where [O] is the number density of O and k_O is a constant. A least-squares fit to the data of six orbits yields the values

$$k_O(732\ \text{nm}) = 2.41\times10^{-8} \pm 5.83\times10^{-10}\ \text{Rayleighs cm}^3 \qquad (3)$$

$$k_{N_2}(732\ \text{nm}) = 5.05\times10^{-19} \pm 1.66\times10^{-20}\ \text{Rayleighs cm}^6. \qquad (4)$$

The uncertainty of the fitting is 3% for k_O and k_{N_2}.

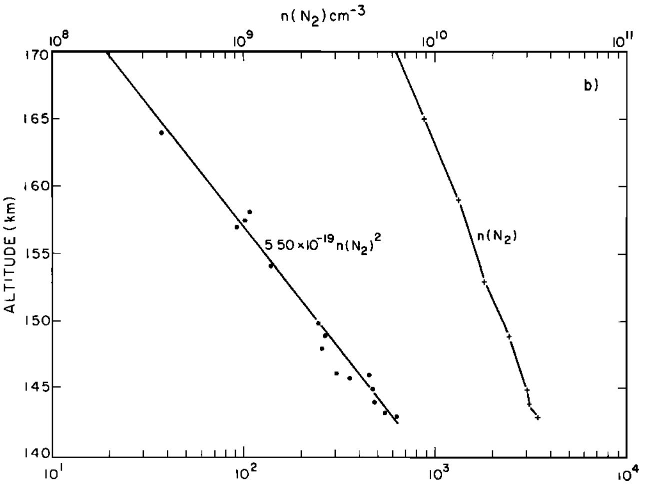

Fig. 4b. As for Fig. 4a on orbit 1311.

Atmosphere Explorer Glow at Shorter Wavelengths

The photometer on board the Atmosphere Explorer satellites also provided data in wavelength bands centered at 656, 520, 428, 337 and 280 nm. At the shorter wavelengths, the glow is weaker but we were able to separate out the contributions from the oxygen and nitrogen mechanisms to the emission at 656, 337 and 280 nm, though the uncertainties in the derived parameters k_O and k_{N2} are larger than for 732 nm. For 428 nm and 337 nm simultaneous measurements of the neutral particle concentrations are not available and we used the data obtained on contiguous orbits. For 428, 337 and 280 nm data were available on only one orbit.

The derived values of k_O and k_{N2} and the associated uncertainties are given in Table 1, and their ratios relative to 732 nm in Table 2. Value of the rate coefficients per unit wavelength, $k_O/\Delta\lambda$ and $k_{N2}/\Delta\lambda$, where $\Delta\lambda$ is the wavelength span of the band pass are also listed. The N_2 coefficients decrease much more rapidly

TABLE 2. Intensity Ratios*

λ(nm)	Theoretical	Empirical			
	O-H recombination	O-mechanism		N_2-mechanism	
		(i)	(ii)	(i)	(ii)
732	1.00	1.00	1.00	1.00	1.00
656	0.18-0.13	0.71	0.68	0.09	0.08
428	0.05-0.03	0.02	0.02	0.06	0.06
337	0.06-0.02	0.05	0.04	0.21	0.17
280	---	0.08	0.03	0.19	0.08

* (i) $k(\lambda)/k(732\ \text{nm})$ (ii) $k(\lambda)/k(732\ \text{nm})\Delta\lambda$

with wavelength than the O coefficients giving rise to a steeper glow spectrum at low altitudes.

Discussion

In Table 2, the spectral variation of the oxygen mechanism is compared to that predicted from the surface recombination of oxygen and hydrogen atoms [Langhoff et al., 1983]. The predicted intensity ratios and the measured values are in acceptable agreement with the exception of the 732 nm/656 nm ratio. Although the predicted 732 nm/656 nm ratio is particularly uncertain because of possible contributions from the 12-5P1(5) and 14-6R1(1) lines of OH to the band pass at 656 nm, the discrepancy strongly suggests that another mechanism is causing luminosity which is most intense in the region around 700 nm. A plausible candidate is the mechanism responsible for the Shuttle glow [Mende et al., 1985; Swenson et al., 1985] and we suggest that the Atmosphere Explorer glow at high altitudes consists of two components, one arising from surface recombination of O and H into excited states of OH and the other from the Shuttle mechanism which has been attributed [Mende et al., 1985; Swenson et al., 1985] to the continuum produced by the recombination of NO and O.

At low altitudes a third component becomes significant. Its intensity is proportional to the square of the N_2 density or equally well to the product of any pair of the densities of N_2, O_2 and NO. A variation as $[N_2]^2$ is consistent with the mechanism postulated by Green [1984] though the ion mass spectrometer measurements of Engebretson et al. [1980] on the Atmospheric Explorers do not indicate that significant dissociation of the impacting N_2 molecules occurred.

It is possible that with some contribution from the second positive system at 337 nm the Green mechanism could reproduce the measured spectrum. At longer wavelengths, it bears some similarity to emission in the first positive system though it differs in detail from the laboratory spectrum arising from electron impact excitation [Torr and Torr, 1985]. Whatever the mechanism if it is to make a significant contribution to the Shuttle glow its efficiency k_{N_2} must be of orders of magnitude larger for the Shuttle glow than the values we have derived for the Atmosphere Explorer satellites.

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